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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G02B 6/08, 6/12

A1

(11) International Publication Number: WO 99/46618

(43) International Publication Date: 16 September 1999 (16.09.99)

(21) International Application Number: PCT/US99/05092

(22) International Filing Date: 9 March 1999 (09.03.99)

(30) Priority Data:

60/077,348	9 March 1998 (09.03.98)	US
09/263,885	8 March 1999 (08.03.99)	US

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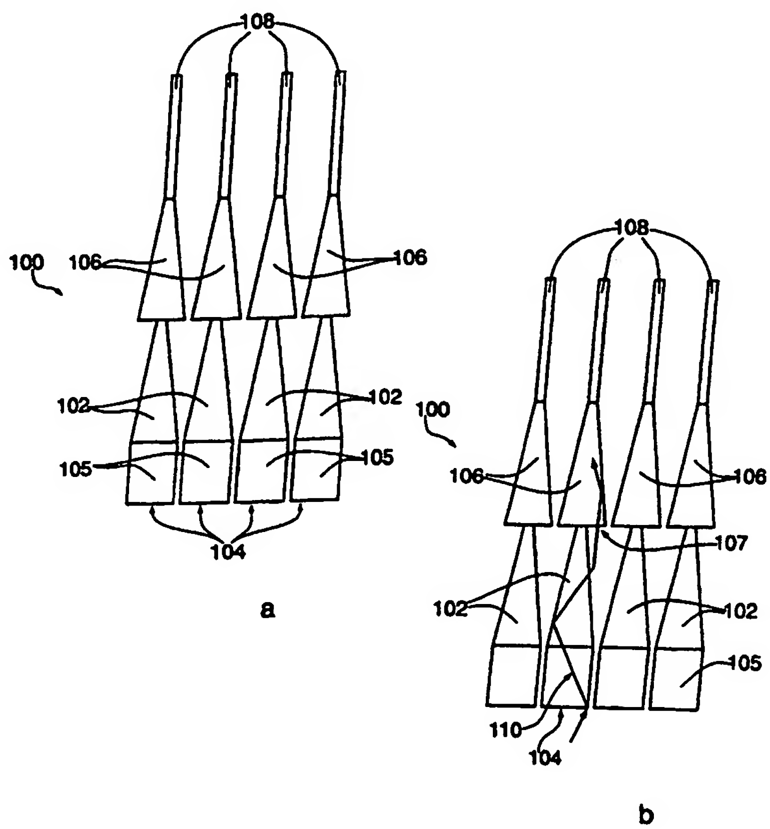
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: OPTICAL WAVEGUIDE STRUCTURE INCLUDING CASCADED ARRAYS OF TAPERED WAVEGUIDES

(57) Abstract

A waveguide structure comprising a plurality of cascaded arrays of tapered waveguides which are operably coupled to one another. The tapered waveguides are each characteristically arranged so as to taper from a wide end to a narrow end along a direction light propagation through the tapered waveguides. This cascaded arrangement increases the pickup of primarily on-axis light (i.e., input light that is substantially parallel to axes of the tapered waveguides) and the rejection of off-axis light (i.e., input light that is outside of a certain angular range relative to the axes of the tapered waveguides). In order to prevent recapture of the rejected light, one or more solutions are provided according to the present invention. The waveguide structure may be curved out of the plane containing the cascaded tapered waveguides, or straight waveguides may be provided between the tapered waveguides so as to increase the distance therebetween. In addition, secondary tapered waveguides may be provided between adjacent cascaded tapered waveguides so as to redirect rejected light in a manner that decreases the likelihood of recapture in the light propagating path.



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OPTICAL WAVEGUIDE STRUCTURE INCLUDING CASCADED ARRAYS OF TAPERED WAVEGUIDES

Field of the invention:

The present invention relates in general to light propagating waveguide structures comprising cascaded arrays of tapered waveguides. More specifically, the present invention relates to waveguide structures for transmitting a scanned image in an optical device. The present invention particularly relates to a waveguide structure which is adapted to reject light outside of a preferred angular zone, since the rejected light represents noise relative to a desired image-carrying light input within the preferred angular zone.

Description of related art:

The use of optical waveguide structures in connection with optical scanning of images and the like is generally known. Such waveguide structures generally guide an image, as propagating light, to an optical device, such as an optical detector.

Preferably, the waveguide structure must provide a significant depth of field (for example, a modulation transfer function ("MTF") greater than about 50% at a distance of 4 mm between the waveguide structure and the page or object being scanned). However, it is difficult to maintain a required amount of light gathering power and still provide the required depth of field. In particular, the waveguide structure must

collect normal (or "on-axis") input rays (i.e., rays parallel or almost parallel to axes of the waveguides in the waveguide structure) and reject input rays forming more than a certain angle with the axes of the waveguides (sometimes referred to hereinbelow as "off-axis" light). For example, in a waveguide structure in a 600 dots-per-inch "dpi" scanner, input rays forming an angle of more than about 0.6° (preferably, more than about 0.4°) relative to the axis of the waveguide structure must be rejected. This is problematic, however, because the rejected light represents most of the light emanating from the scanned object. Moreover, if even a relatively small amount of the unwanted light reaches the detector (or other operative optical device), the resultant signal-to-noise ratio may deteriorate significantly. Accordingly, suitable means for minimizing the amount of unwanted light reaching the detector or the like is desirable.

Summary of the invention:

Accordingly, the present invention is generally directed to a waveguide structure wherein input light outside of a desired angular range is rejected from the waveguide structure. In addition, the rejected light is additionally kept from being recaptured "downstream" in the waveguide structure.

Specifically, the present invention uses an array of first tapered waveguides operably coupled with at least an array of second tapered

waveguides, each second tapered waveguide corresponding with a respective first tapered waveguide. This structure has been found to desirably select only the low angle light (i.e., the light within the desired angular range relative to axes of the waveguides) from the object being scanned.

In general, however, light rejected by the first tapered waveguides may be undesirably recaptured by the second (third, fourth, etc.) tapered waveguides downstream. To address this issue, recapture of the rejected light may be avoided by providing additional tapered waveguides in the cladding region of the waveguide structure. In general, these additional tapered waveguides operate to guide the light away from input regions of the second (third, fourth, etc.) tapered waveguides.

Also, straight (i.e., non-tapered) waveguides may be provided between the first tapered waveguides and respective second tapered waveguides to avoid recapture. By increasing a distance between the arrays of tapered waveguides, the light rejected from the first tapered waveguides has a longer distance over which it is spread out and dispersed in the cladding of the waveguide structure. In addition, if a light-absorbing overcladding is provided, the rejected light may be absorbed thereby.

Another feature of the present invention is that the additional tapered waveguides (i.e., in addition to the cascaded and operably

connected arrays of first, second, third, fourth, etc. tapered waveguides) discussed above can be used in combination with the use of straight waveguides between the first, second, third, fourth, etc. tapered waveguides. Such a combination further minimizes the recapture of rejected light.

In addition to the above, the waveguide structure according to the present invention may be provided with a curved configuration that also helps to prevent recapture of rejected light.

As an alternative to providing secondary tapered waveguides and/or straight waveguides between the arrays of tapered waveguides, a waveguide structure may be provided that includes an array of first tapered waveguides operably coupled to an array of respective second tapered waveguides, such that the second tapered waveguides have a smaller taper ratio than the first tapered waveguides.

Although the present invention contemplates the use of a cascade of arrays of first, second, third, fourth, etc. tapered waveguides, reference will be made hereinafter only to arrays of first and second tapered arrays for simplicity and brevity. This is because the use of arrays of first and second tapered waveguides can be expanded with the use of an array of third (fourth, fifth, etc.) tapered waveguides.

Brief description of the drawings:

The present invention will be described hereinbelow with reference to the drawings appended hereto, in which:

Figure 1a is a double-taper waveguide structure with arrays of first and second tapered waveguides;

Figure 1b illustrates a path of a light ray propagated and recaptured in the waveguide structure of Figure 1a;

Figures 2a-2c illustrate a double-taper waveguide structure including an array of secondary tapered waveguides according to the present invention;

Figure 3 is a double-taper waveguide structure including straight waveguides interposed between arrays of first and second tapered waveguides according to the present invention;

Figure 4 is a double-taper waveguide structure including both an array of secondary tapered waveguides and straight waveguides interposed between arrays of first and second tapered waveguides, according to the present invention;

Figure 5 is a triple-taper waveguide structure including straight waveguides interposed between arrays of first, second, and third tapered waveguides;

Figure 6 is an in-plane curved double-taper waveguide structure according to the present invention, in which first and second tapered waveguides have different taper ratios, respectively;

Figure 7 is an illustrative cross-sectional view of a waveguide, illustrating a core and cladding structure thereof; and

Figure 8 is a cross-sectional side view of an out-of-plane curved waveguide structure according to the present invention.

It is expressly noted that the drawings appended hereto are meant to be illustrative only, and are not to be construed as limiting the invention defined in the claims appended hereto. In particular, the drawings are not necessarily drawn to a consistent scale, either within each drawing or amongst the respective drawings.

Detailed description of the present invention:

Figure 1a is a plan view of a double-taper waveguide structure 100 according to the present invention. Waveguide structure 100 includes a first array of first tapered waveguides 102 having respective input ends 104 where image-carrying light is received. The array of first tapered waveguides 102 is optically coupled to an array of second tapered waveguides 106. As illustrated in Figures 1a, 1b, the first tapered waveguides 102 and second tapered waveguides 106 are coupled directly to each other.

The first tapered waveguides 102 and the second tapered waveguides 106 taper from a wide end to a narrow end along the direction of light propagation in the waveguide structure 100. Preferably, the narrow ends of the first tapered waveguides are coupled

to a relatively central portion of the wide ends of the second tapered waveguides 106. In Figures 1-5, the array of second tapered waveguides 106 is shown to have the same size and shape as the array of first tapered waveguides 102. This is not always necessarily so (see, for example, Figure 6).

The respective first tapered waveguides 102 may each be operably coupled to a straight (i.e., non-tapered) waveguide 105. Straight waveguides 105 are not required according to the present invention. Straight waveguides 105 preferably are as wide as the wide ends of the first tapered waveguides 102. The waveguide structure may further include straight (i.e., non-tapered) waveguides 108 coupled to respective narrow ends of the second tapered waveguides 106, as illustrated in Figures 1a, 1b.

The mention of "straight waveguides" throughout this application is meant to draw a contrast with the mention of tapered waveguides.

As mentioned above, the waveguide structure 100 having cascaded arrays of first and second tapered waveguides 102, 106 is effective for collecting normal light rays (i.e., rays entering input ends 104 parallel or nearly parallel to the respective optical axes of the tapered waveguides) and rejecting out-of-axis light rays (i.e., input rays forming an angle larger than a predetermined angle (about 0.6° and preferably about 0.4° for a 600 dpi scanner) with the respective optical axes of the tapered waveguides).

However, as also mentioned above, the waveguide structure 100 may allow light rejected from the first tapered waveguides 102 to be recaptured by respective ones of the second tapered waveguides 106. Specifically, Figure 1b illustrates a light ray 110 that is received at an end 104 and that is rejected from the tapered side of the first tapered waveguide 102. Thereafter, however, the light ray 110 is recaptured by the wide end 107 of the associated second tapered waveguide 106, so as to reenter the light propagation path. Since, as discussed above, such a light ray corresponds to noise, the signal-to-noise ratio of a scanned image or the like deteriorates significantly. For greater simplicity in visualizing the operation of the waveguide structures being disclosed, the operative concepts are illustrated herein using light rays and classical ray optics. However, it will be understood by those skilled in the art that the tapered waveguide structures disclosed herein may be very small, so that conventional beam propagation methods and concepts may also be needed to further fully describe the operation of the waveguides being disclosed.

One solution to the problem of the present invention illustrated in Figure 1b is illustrated in Figure 2a. Specifically, Figure 2a illustrates a waveguide structure 100', which generally includes cascaded arrays of first and second tapered waveguides 102, 106 as in Figures 1a, 1b, but further includes an array of secondary tapered waveguides 112. The secondary tapered waveguides 112 are arranged

alternatingly between the first tapered waveguides 102, adjacent the respective narrow ends of the first tapered waveguides 102. Like first and second tapered waveguides 102, 106, each secondary tapered waveguide 112 tapers along the direction of light propagation in the waveguide structure from a wide end to a narrow end. Preferably, the respective narrow ends of the secondary tapered waveguides 112 are arranged between gaps between respective second tapered waveguides 106, as seen in Figure 2a. As in Figures 1a, 1b, waveguide structure 100' may also include straight waveguides 105, 108.

As illustrated in Figure 2a, light ray 110" is rejected from first tapered waveguide 102 and is deflected by secondary tapered wave guide 112 into the gap or space between adjacent second tapered waveguides 106, and then into second tapered waveguide 106 at a sufficiently high angle so as to exceed TIR ("total internal reflection") conditions. These conditions are calculable for a given waveguide according to known principles of physics and optics. Therefore, ray 110" cannot be maintained (i.e., retained in) second tapered waveguide 106 and is desirably rejected therefrom, as illustrated.

Figure 2b illustrates a second mode of operation of the arrangement illustrated in Figure 2a. In this situation, a light ray 110''' is rejected from first tapered waveguide 102 as before, but at a slight enough angle so as to reenter second tapered waveguide 106. Once inside second tapered waveguide 106, the ray 110''' is reflected at an

angle insufficient to exceed TIR conditions. Therefore, the ray 110''' is undesirably propagated in second tapered waveguide 106.

To address the problem illustrated in Figure 2b, a plurality of large and small secondary tapered waveguides may be provided, as shown in Figure 2c. Waveguide structure 100" includes large secondary tapered waveguides 112a and small secondary tapered waveguides 112b. Like secondary tapered waveguides 112 in Figures 2a and 2b, large secondary tapered waveguides 112a are located between adjacent first tapered waveguides 102, as shown in Figure 2c. In addition, small secondary tapered waveguides 112b are provided on either side of each large secondary tapered waveguide 112a. Each small secondary tapered waveguide 112b is coupled directly to a portion of the wide end of a respective second tapered waveguide 106.

As illustrated in Figure 2c, small secondary tapered waveguides 112b act to help change the angle at which a light ray 113 enters second tapered waveguide 106, so that the ray 113 can be rejected from second tapered waveguide 106.

Another solution to the problem illustrated in Figure 1b is illustrated in Figure 3. Waveguide structure 200 includes an array of first tapered waveguides 202 and an array of second tapered waveguides 206 coupled to respective first tapered waveguides 202 by straight waveguides 210.

With the arrangement illustrated in Figure 3, a light ray 212 may be rejected from a first tapered waveguide 202 in a manner similar to that described previously. However, the first and second tapered waveguides 202, 206 are spaced farther apart from each other than in Figures 1a, 1b, or 2a-2c because of straight waveguides 210 interposed therebetween. Accordingly, light ray 212 has a greater chance of being absorbed or scattered (as indicated at 214) before it can be recaptured by second tapered waveguide 206.

Waveguide structure 200 may include straight waveguides 205 and 208. Straight waveguides 205 are not necessary for the present invention to function as desired.

Figure 4 is a double-taper waveguide structure 200' which is similar to waveguide structure 200, with the additional provision of secondary tapered waveguides 216. With this arrangement, a rejected light ray 212 may be absorbed or partially absorbed in region 214. Any residual light therefrom may be captured by a secondary tapered waveguide 216, which guides the residual light through a gap between adjacent second tapered waveguides 206, in a manner similar to that described above relative to Figures 2a-2c. Thereafter, the residual light may be further absorbed in region 214', as shown in Figure 4.

Figure 5 illustrates a triple-taper waveguide structure 300 (which is similar in structure to that illustrated in Figure 3). Waveguide structure 300 includes an array of first tapered waveguides 302

operably coupled (by way of straight waveguides 304) to an array of second tapered waveguides 306. The array of second tapered waveguides 306 is in turn operably coupled by way of straight waveguides 308 with an array of third tapered waveguides 310. Straight waveguides 312 may be provided at an opposite end of third tapered waveguides 310 and straight waveguides 305 may be operably coupled to first tapered waveguides 302, as shown in Figure 5. As before, straight waveguides 305 are not essential to the operation of the present invention.

Waveguide structure 300 functions in a manner similar to that of waveguide structure 200 in Figure 3, so a detailed explanation thereof is not repeated here.

Figure 6 illustrates an in-plane curved waveguide structure 400, which is somewhat similar to waveguide structure 100 illustrated in Figures 1a, 1b. However, neither secondary tapered waveguides nor straight waveguides between the first and second tapered waveguides are provided. Instead, first tapered waveguides 402 are directly coupled to corresponding second tapered waveguides 404. However, according to this aspect of the present invention, the second tapered waveguides 404 characteristically have a taper ratio (a ratio of $Width_{input}/Width_{output}$) that is smaller than that of first tapered waveguides 402. This feature allows the gaps between the second tapered waveguides 404 to be larger, so that light that is rejected by first tapered waveguides 402 is

less likely to be recaptured by second tapered waveguides 404. In addition, the in-plane curvature of the waveguide structure 400 allows desired light to be propagated in one direction (i.e., following the light propagation paths of the respect waveguide cascades, shown generally at A) while the light rejected therefrom is transmitted in another direction (shown generally at B).

Figure 7 is a simplified cross-sectional view of the structure of the waveguide structures discussed above. It is noted that Figures 1a, 1b, and 2-6 illustrate only the waveguides of the respective waveguide structures, in order to simplify the views. However, Figure 7 clearly shows the provision of cladding about a waveguide core. Specifically, a molded or embossed cladding first layer 600 includes a groove 608 formed therein by known technology and/or according to the disclosure contained in the co-pending U.S. patent application of Shacklette and Beeson, filed March 4, 1999 and entitled "Waveguide Having Cladding that Exhibits Unfilled Skin Effect" (Atty. Docket No. 30-4445a(4290)). The entire contents of that co-pending application are incorporated herein by reference.

A light-transmitting material for forming the waveguide core 606 is provided in the groove 608. A second cladding layer 602 is formed thereover, and a light absorbing black layer 604 is formed over top cladding layer 602. It is specifically noted that light can propagate

through the material used for forming first and second cladding layers 600, 602.

Figure 8 illustrates an out-of-plane curved waveguide structure 800. The term refers to the curvature of the waveguide structure 800 out of a plane in which the cascaded tapered waveguides lie generally parallel to one another. As mentioned with respect to Figure 7, the waveguide structure 800 includes a black layer 802, a first cladding 812, a layer 814 in which the cascaded tapered waveguides are formed, a second cladding 816. First and second tapered waveguides 804 and 806 are formed in layer 814.

By bending the waveguide structure out of the plane of the waveguides, the rejection of unwanted off axis light is enhanced, as noted by rays 810. This is a similar effect as that provided in Figure 6.

Thus, while there have been shown and described and pointed out fundamental novel features on the invention as applied to preferred embodiments thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices illustrated, and in their operation, and in the method illustrated and described, may be made by those skilled in the art without departing from the spirit of the invention. For example, it is expressly intended that all combinations of those elements and/or methods steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. It is the invention,

therefore, to be limited only as indicated by the scope of the claims appended hereto.

WHAT WE CLAIM IS:

1. An optical waveguide structure comprising:

an array of first tapered waveguides; and

an array of second tapered waveguides each operably coupled to a respective one of said first tapered waveguides;

wherein said first and second tapered waveguides both are tapered from respective wide ends thereof to respective narrow ends thereof along a direction of light propagation therethrough, such that said narrow ends of said first tapered waveguides are operably coupled to respective wide ends of said second tapered waveguides.

2. The structure according to claim 1, further comprising:

an array of non-curved waveguides coupled to respective said narrow ends of said second tapered waveguides.

3. The structure according to claim 1, further comprising an array of straight waveguides coupled to respective said wide ends of said first tapered waveguides.

4. The structure according to claim 1, further comprising an array of secondary tapered waveguides each arranged between adjacent said first tapered waveguides.

5. The structure according to claim 4, wherein said secondary tapered waveguides are each arranged between adjacent said narrow ends of said first tapered waveguides.

6. The structure according to claim 4, wherein said secondary tapered waveguides comprise relatively large secondary tapered waveguides and relatively small secondary tapered waveguides, wherein said relatively large secondary tapered waveguides are each arranged between adjacent said first tapered waveguides and said relatively small secondary tapered waveguides are coupled to respective said wide ends of said second tapered waveguides.

7. The structure according to claim 6, wherein said relatively large secondary tapered waveguides are arranged between respective said narrow ends of said first tapered waveguides.

8. The structure according to claim 6, wherein said relatively small secondary tapered waveguides are coupled to respective said wide ends of said second tapered waveguides on either side of a region at which said first and second tapered waveguides are operably coupled to one another.

9. The structure according to claim 1, comprising an array of straight waveguides operably coupling said first tapered waveguides to respective said second tapered waveguides so as to space apart said first and second tapered waveguides.

10. The structure according to claim 9, comprising an array of secondary tapered waveguides each arranged between adjacent said straight waveguides.

11. The structure according to claim 1, comprising an array of non-tapered waveguides each coupled with respective said narrow ends of said second tapered waveguides.

12. The structure according to claim 11, wherein said non-tapered waveguides are each curved and said first and second tapered waveguides and said curved non-tapered waveguides coupled thereto lie in the same plane.

13. The structure according to claim 1, wherein the structure is curved out of a plane in which said first and second tapered waveguides lie.

14. The structure according to claim 13, comprising a first cladding surrounding a portion of said first and second tapered waveguides, a second cladding covering a remaining portion of said first and second tapered waveguides, and a light-absorbing layer formed over said second cladding.

15. The structure according to claim 1, further comprising an array of third tapered waveguides, each operably coupled to a respective one of said second tapered waveguides, wherein said third waveguides are tapered from respective wide ends thereof to respective narrow ends thereof along a direction of light propagation therethrough, such that said narrow ends of said second tapered waveguides are operably coupled to respective said wide ends of said third tapered waveguides.

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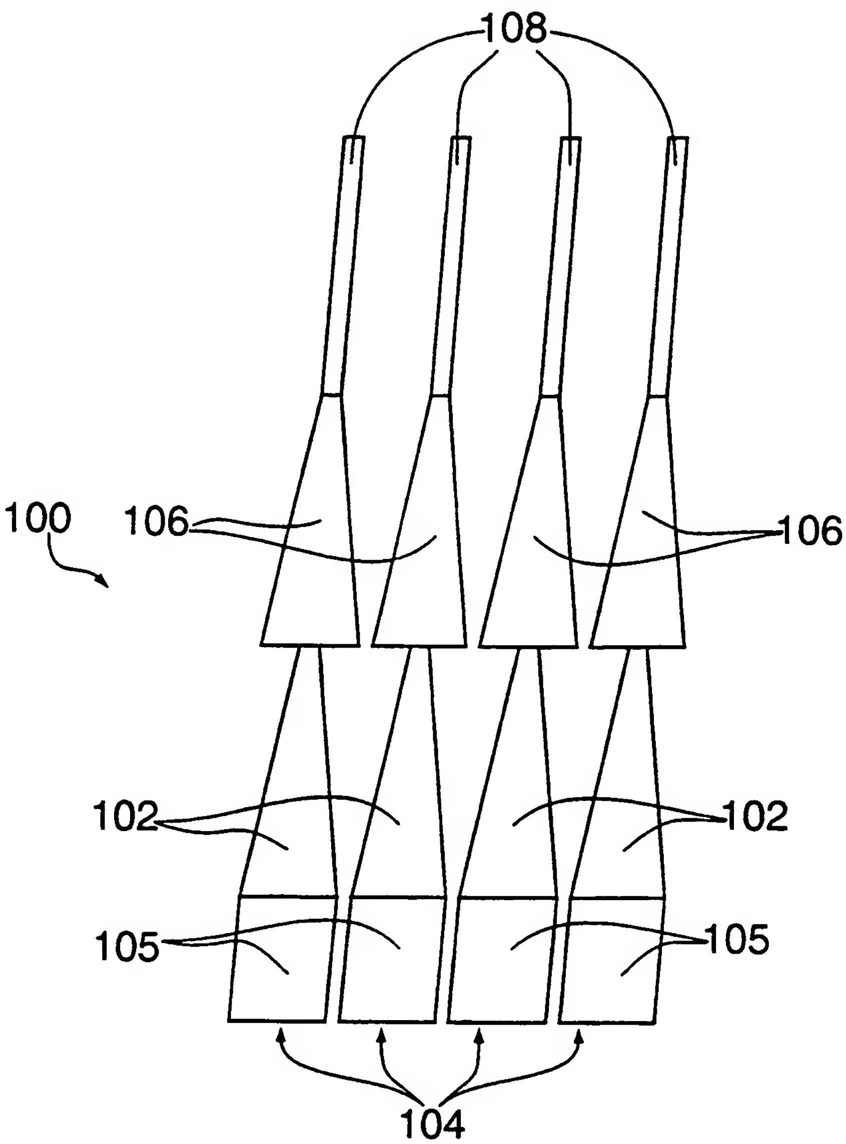

FIG. 1a

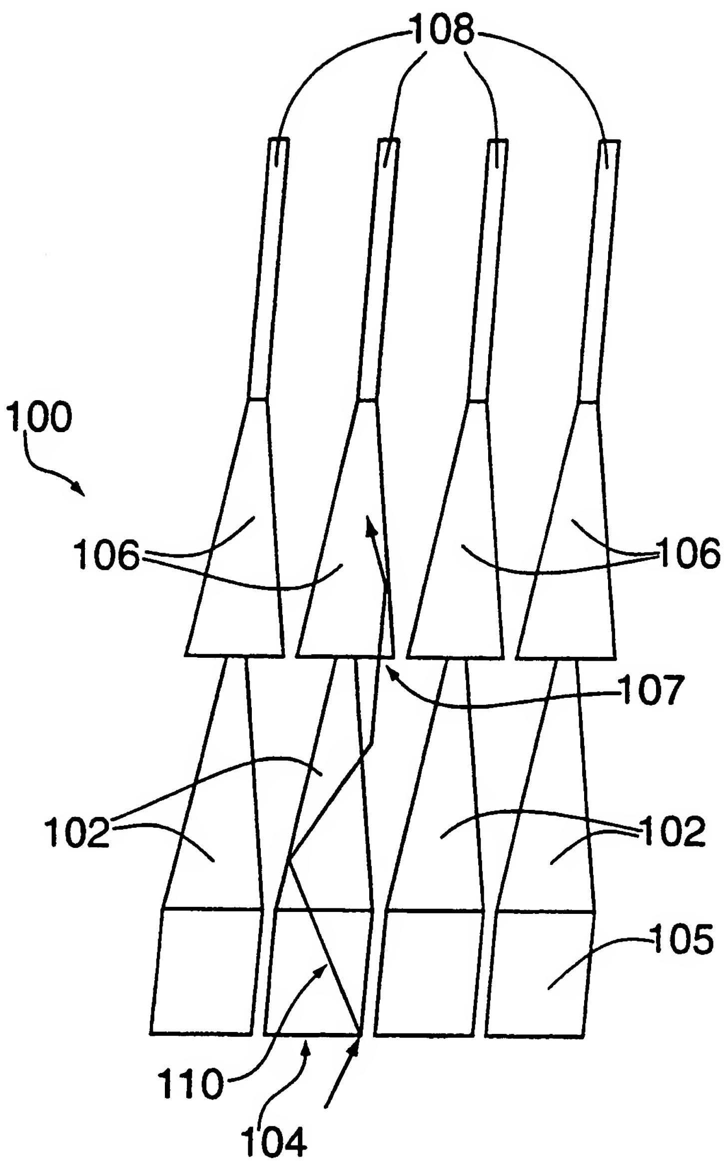

FIG. 1b

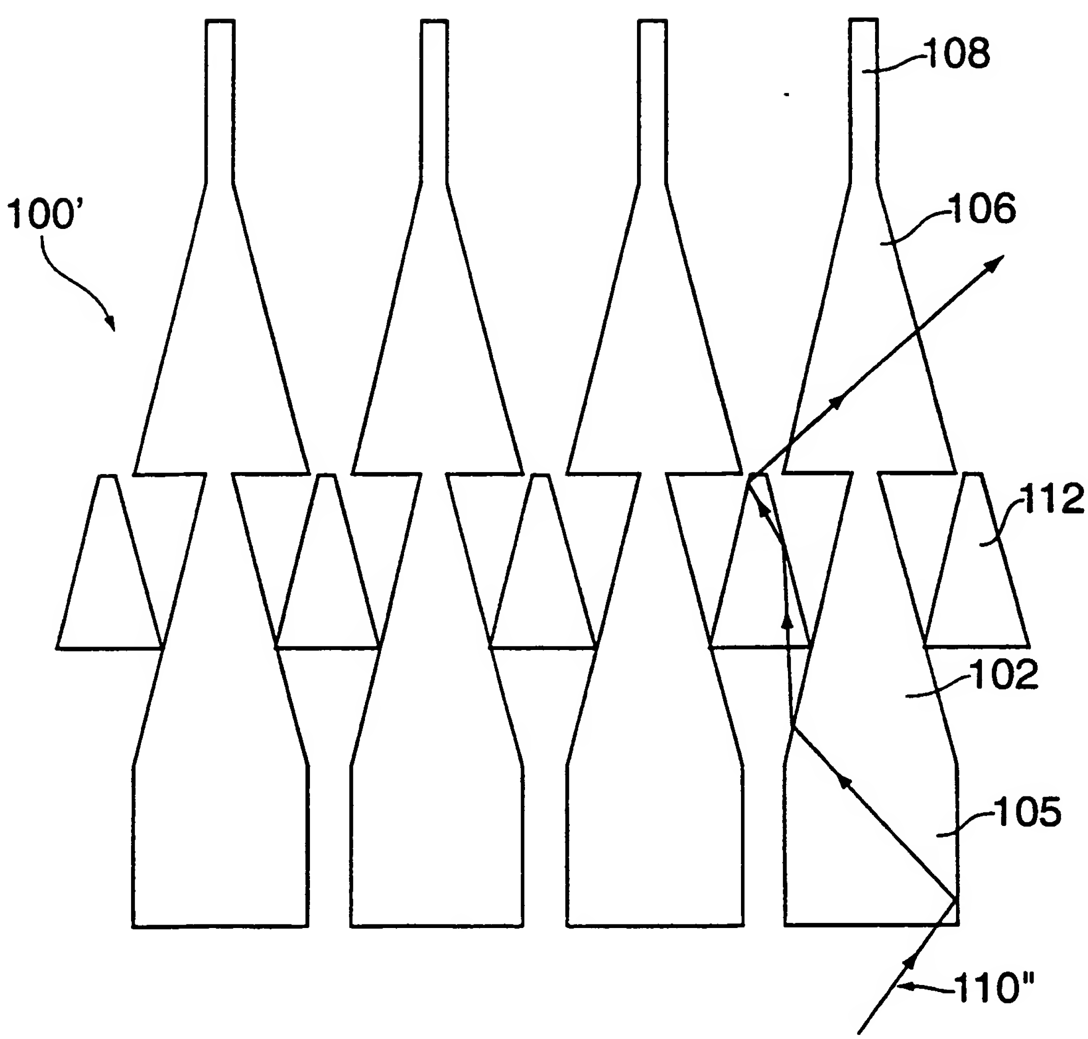

FIG. 2a

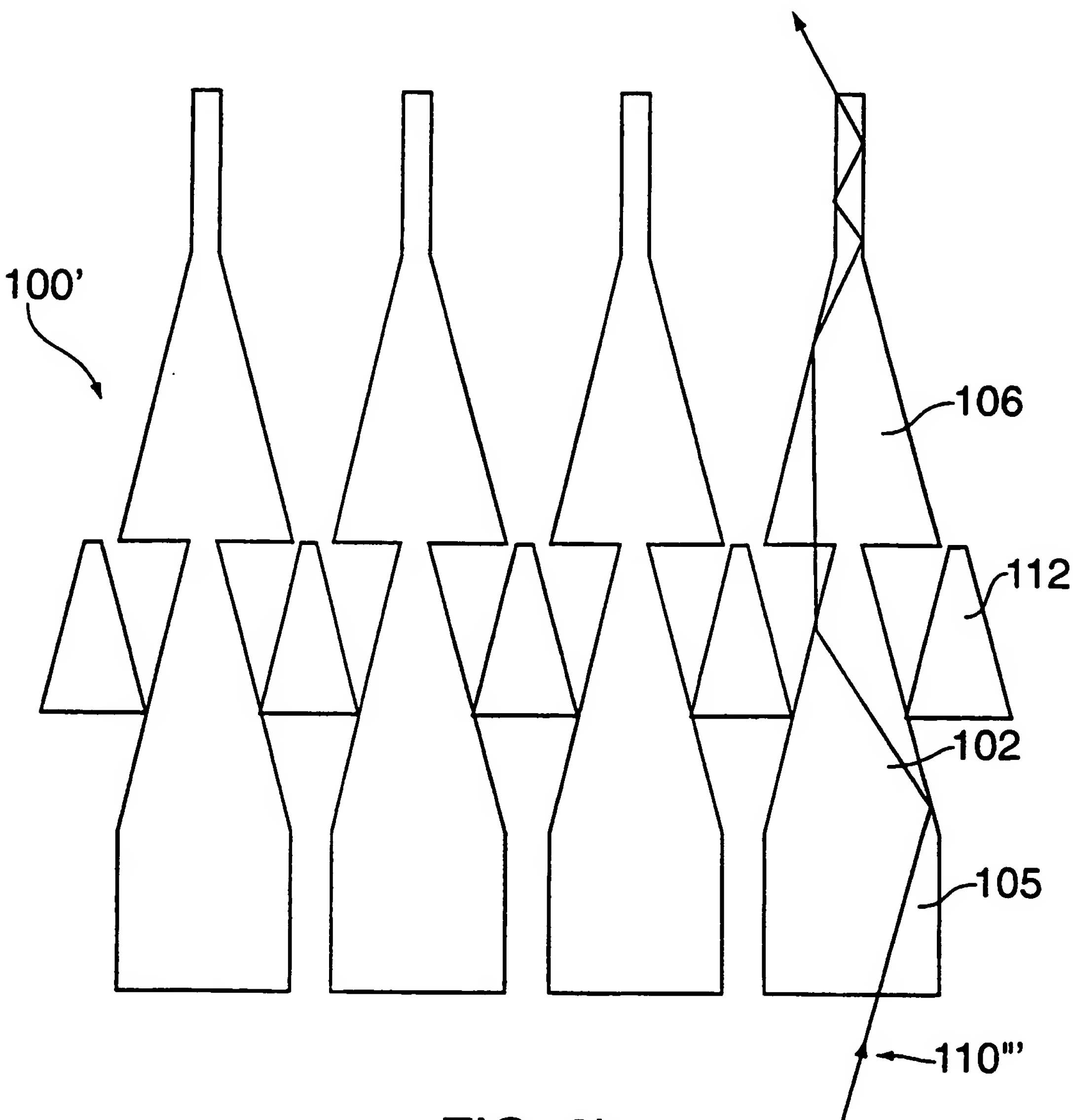

FIG. 2b

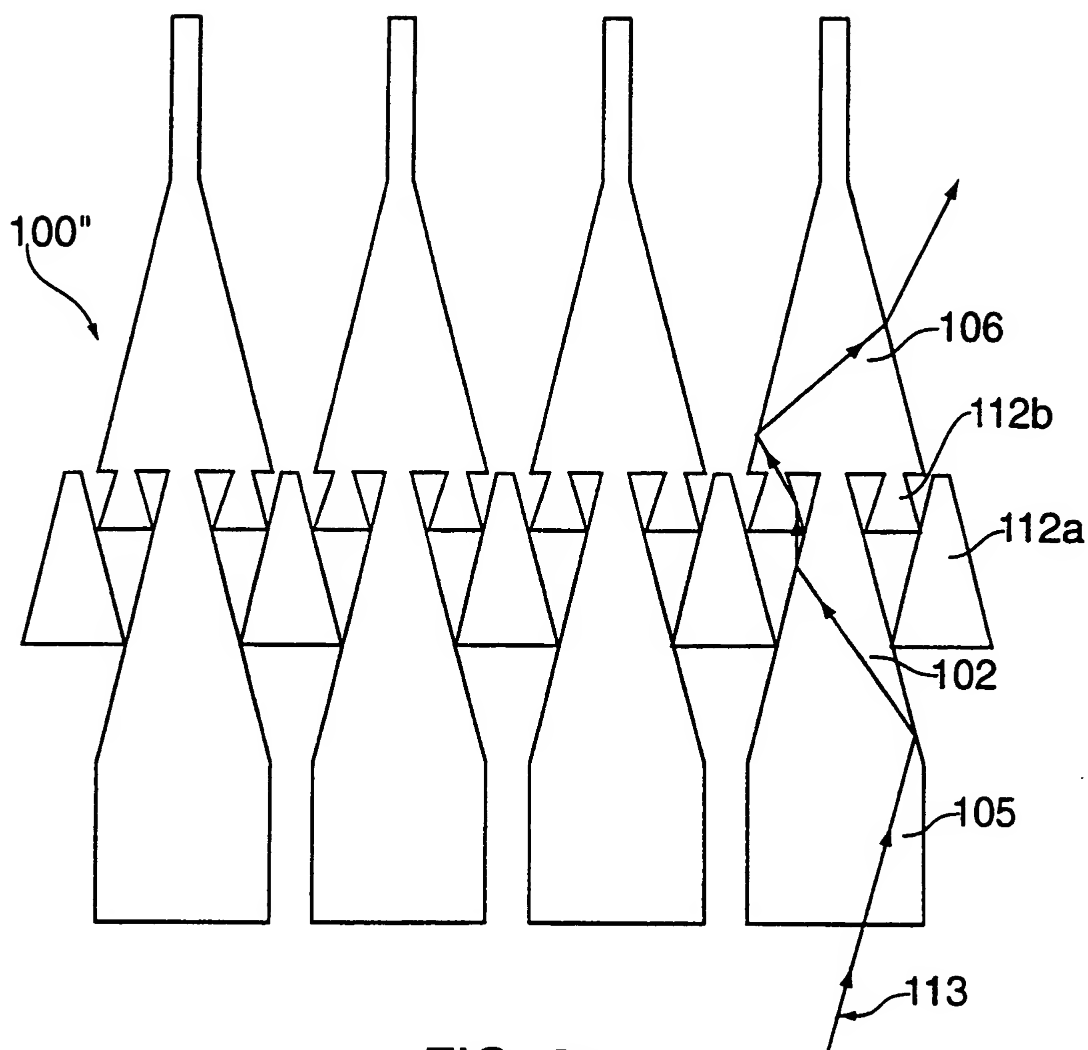

FIG. 2c

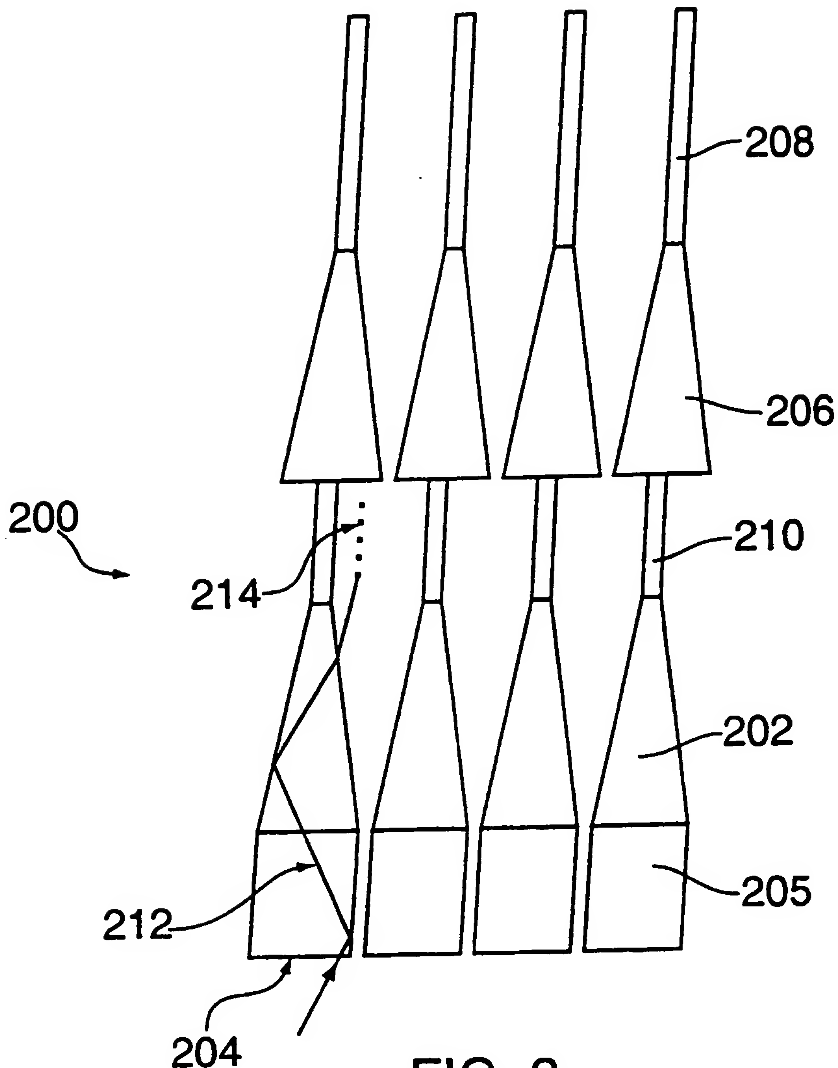

FIG. 3

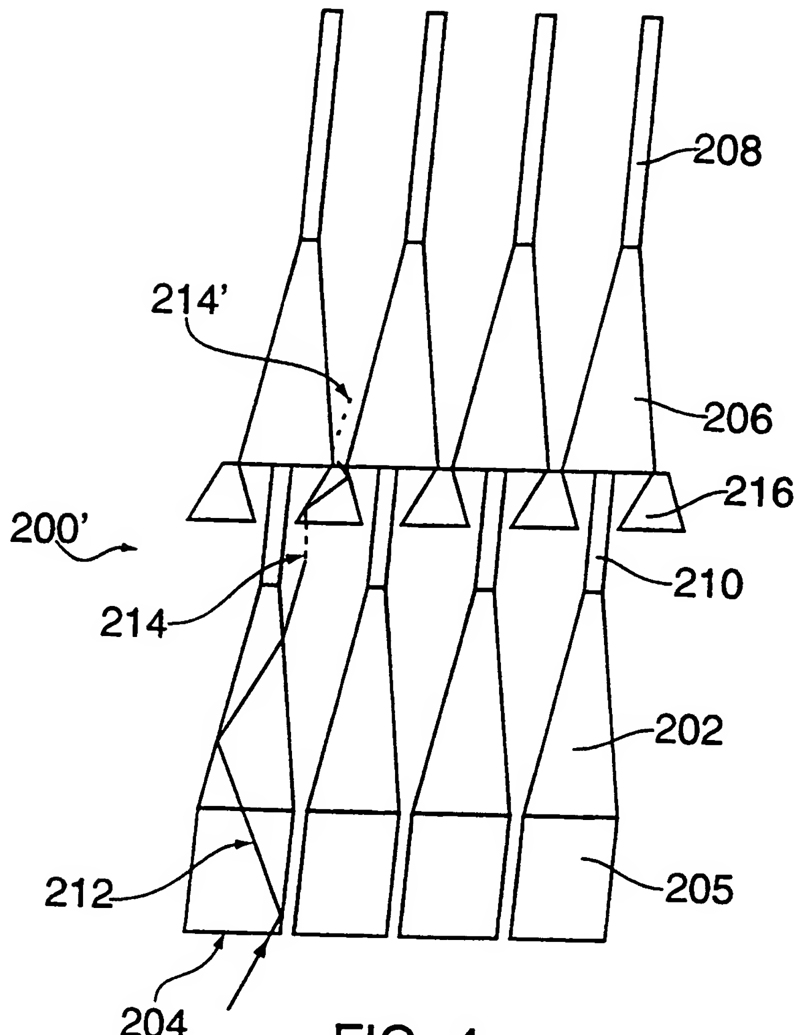

FIG. 4

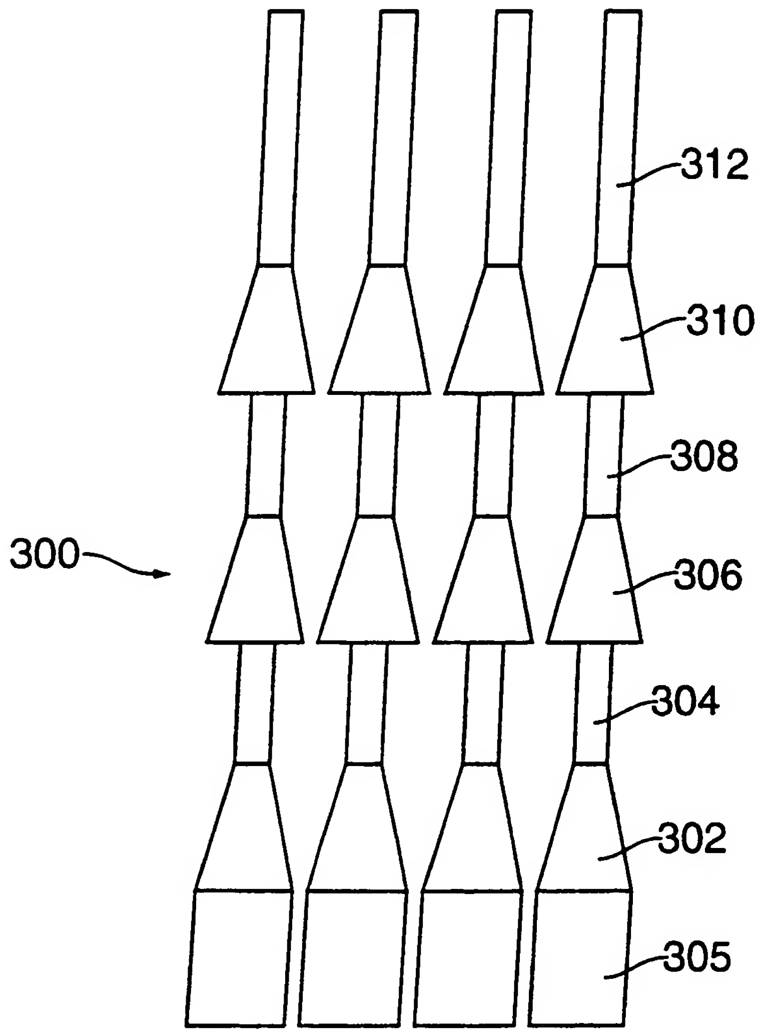

FIG. 5

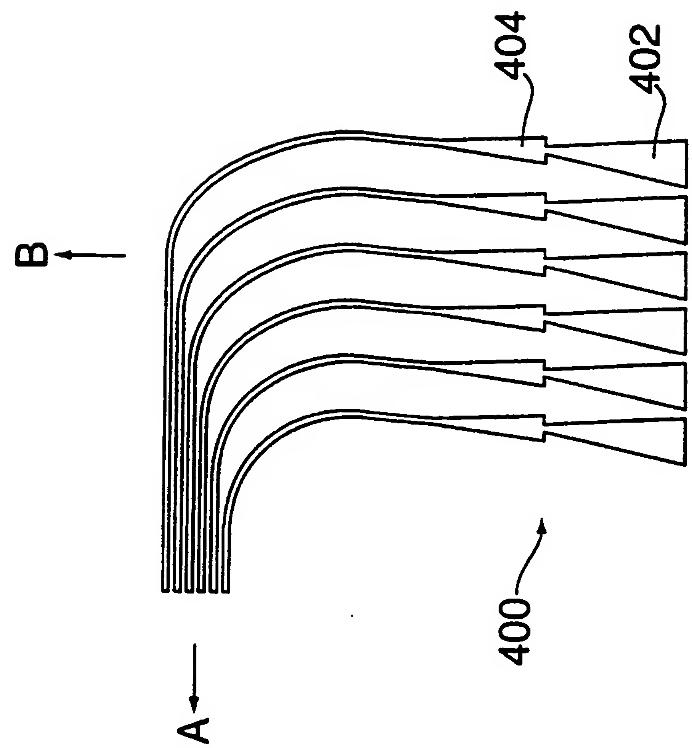

FIG. 6

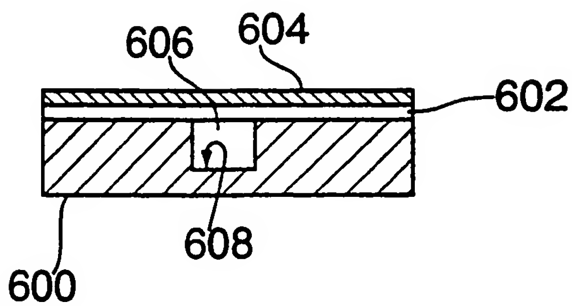

FIG. 7

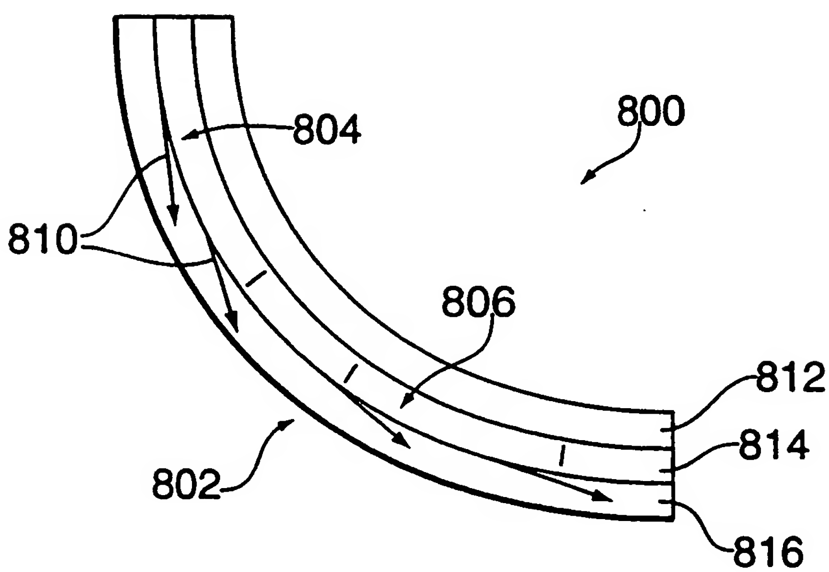

FIG. 8

INTERNATIONAL SEARCH REPORT

Inter al Application No
PCT/US 99/05092

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/08 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B G02F H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 923 276 A (WELLS JAMES A) 8 May 1990 see figure 3	1,9,11
X	US 4 439 029 A (OKURA ZENICHI ET AL) 27 March 1984 see column 3, line 29 - line 63; figures 1,2	1
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[X] Further documents are listed in the continuation of box C.

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INTERNATIONAL SEARCH REPORT

Inter   al Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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